Atmospheric Physics

Multidimensional Simulations of Marine Stratocumulus Clouds

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The effects of aerosols on cloud albedos contributes the single greatest uncertainty in estimates of global radiative forcing since preindustrial times. A dramatic example of these effects is provided by ship tracks, which are long, linear regions of enhanced cloud reflectivity that sometimes form downwind of ships. Previously, ship tracks and a number of other topics in the area of aerosol-cloud interactions have been investigated with a one-dimensional numerical model, which is composed of three components: a size-resolved aerosol and cloud microphysics model, a detailed radiative transfer model, and a turbulent kinetic energy closure scheme. An advantage of using a one-dimensional model is that its computational efficiency allows simulations of processes with long time constants; it also permits large numbers of simulations to test model sensitivities. However, there are shortcomings to a one-dimensional approach. For example, peak supersaturations, which determine the fraction of aerosols that nucleate cloud droplets, are underestimated because of horizontal averaging; and the covariation of vertical winds and supersaturations are oversimplified, resulting in droplet activation at cloud top rather than at cloud base. To overcome these shortcomings, a newly rewritten microphysics model and a multidimensional eddy-resolving dynamics model have been merged with the radiative transfer model.

Also, by simply replacing the subroutines specific to warm cloud (liquid water) microphysics with their ice counterparts, a new model was created that is being used to study upper-troposphere ice clouds such as contrails and subvisible cirrus.

The first topic relevant to marine stratocumulus clouds under investigation with the new model is the collapsing boundary layer. With the one-dimensional model, it was found that when aerosol concentrations are depleted to very low values, cloud-top radiative cooling can no longer support the turbulent mixing that provides surface moisture to the cloud layer and maintains the boundary layer against subsidence of dry, warm, upper-troposphere air. In such a case, the cloud-topped boundary layer collapses to a fog layer driven by surface shear. However, there are questions regarding the time scales involved, which determine how frequently such a mechanism can occur when boundary conditions (such as sea-surface temperature) are changing. Preliminary two-dimensional simulations with the new model confirm previous calculations, as seen in the figure.

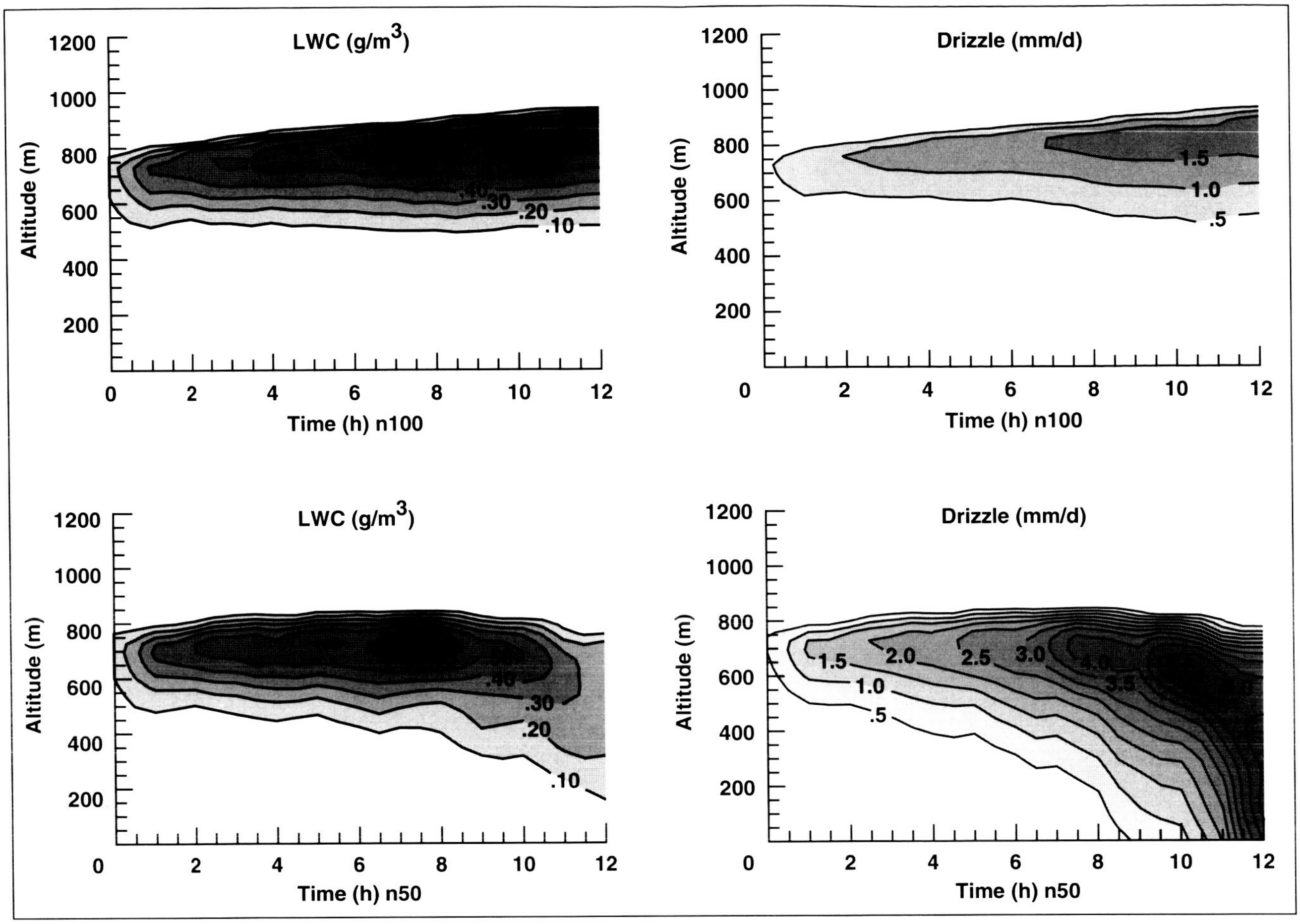

Fig. 1. Time-height contours of horizontally and 2-hour-temporally averaged liquid water mixing ratio (grams per kilogram) and drizzle flux (millimeters per day) in 40 × 40 simulations with initial uniform particle concentrations of 100 (top panels) and 50 (bottom panels) per cubic centimeter.

In the upper (lower) panels the initial particle concentration is 100 (50) per cubic centimeter. In the simulation with lower particle concentrations, the drizzle process develops more rapidly, not only producing a greater sink of cloud water, but also depleting particle concentrations more rapidly. At 18 hours, the maximum droplet concentrations are 52 and 1 per cubic centimeter (a surface source of sea salt particles would likely keep the concentrations from falling much below 5 per cubic centimeter in nature—no consideration of any particle sources was used for these calculations). It is seen that by 18 hours the simulation with a lower initial particle concentration has resulted in a catastrophic collapse of the marine boundary layer.

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